The ENGLISH ELECTRIC JOURNAL

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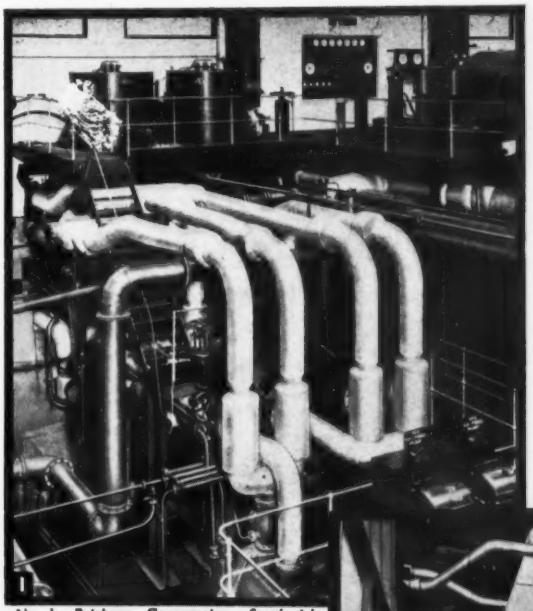
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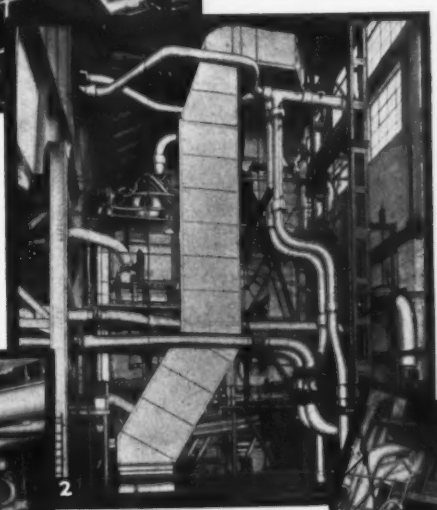
No. 1. Brighton Corporation, Southwick Power Station. Feed Pump Discharge Piping. Steam conditions of 675 lbs./sq. inch at 875°F.
No. 2. Steam and Feed Piping in Boilerhouse at the same station.
No. 3. Corporation of Glasgow, Dalmarnock Power Station. Steam Piping in Boilerhouse. Steam conditions 625 lbs./sq. inch at 850°F.
No. 4. County Borough of Southampton. Pipework in Pump Room. Steam conditions 425 lbs./sq. inch at 820°F.
No. 5. H. J. Heinz Co. Ltd., Harlesden. Steam line to Factory. Steam conditions 160 lbs./sq. inch saturated.
No. 6. Steam and Feed Piping in Boilerhouse at the same station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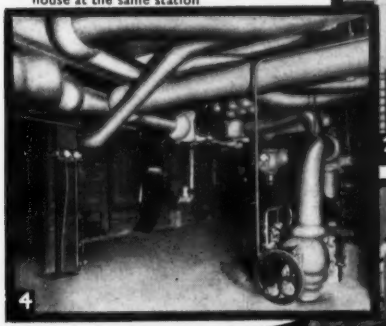
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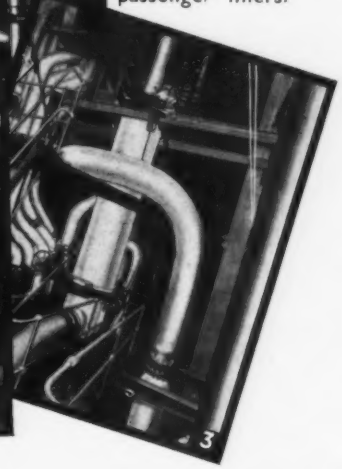
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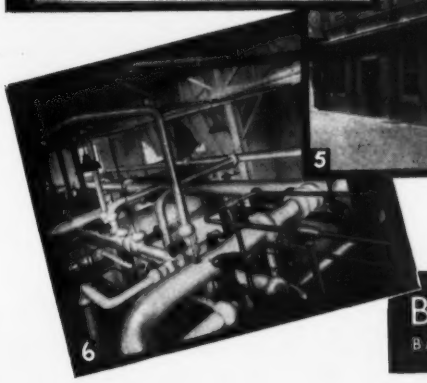
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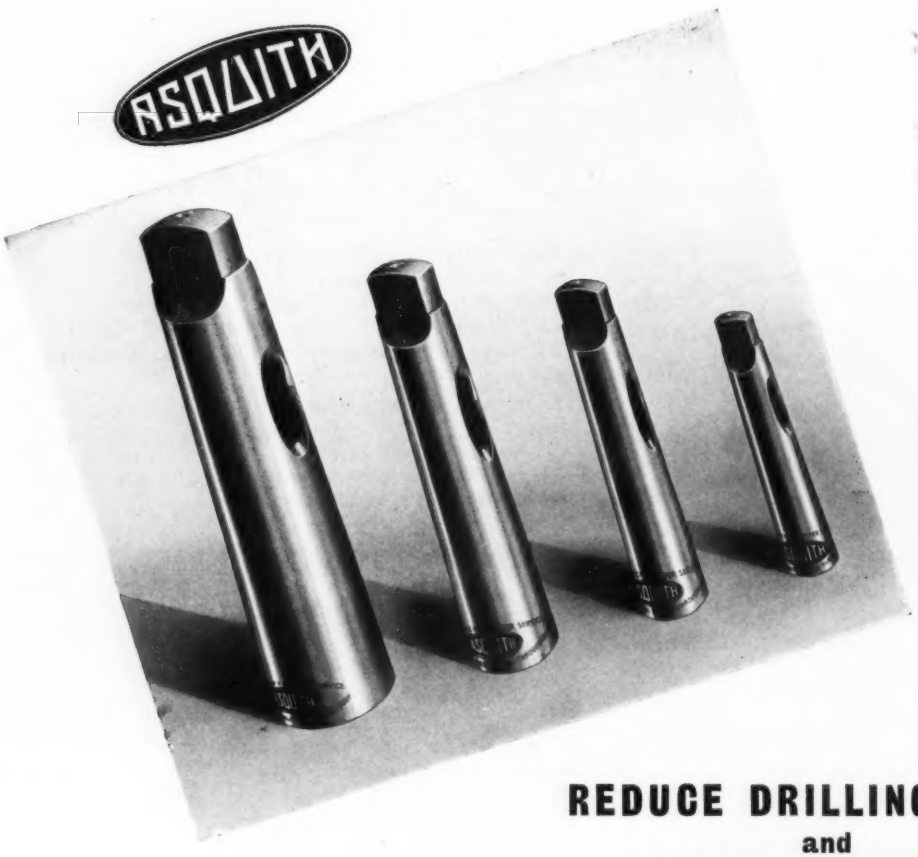

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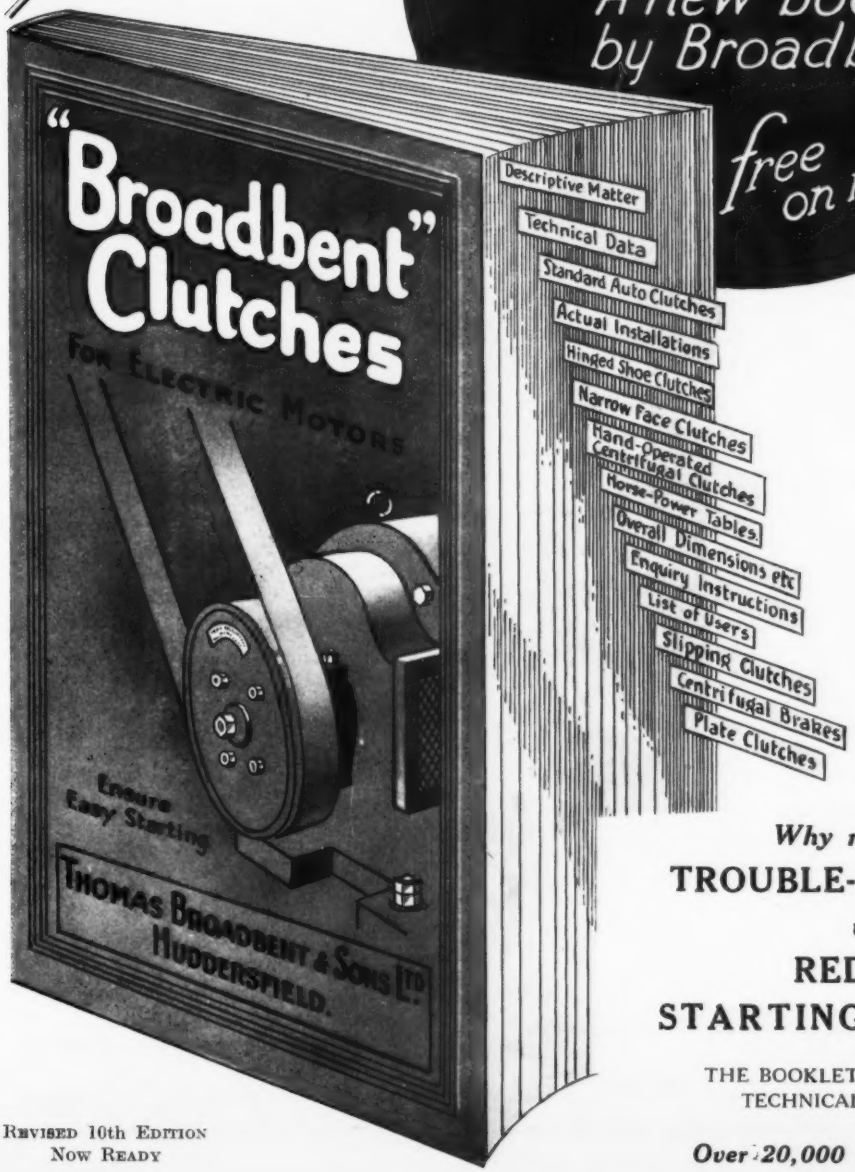

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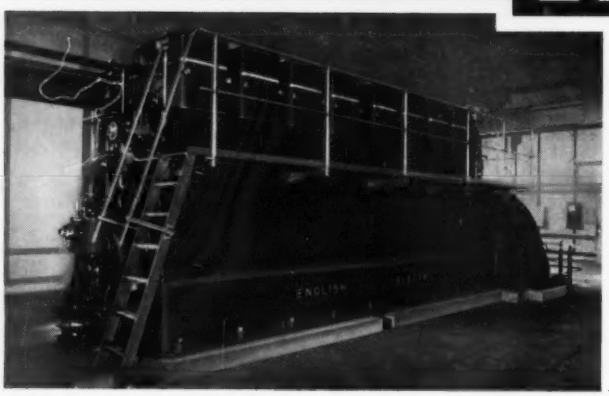

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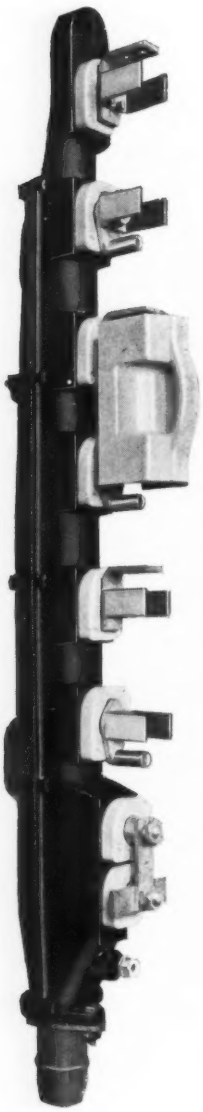

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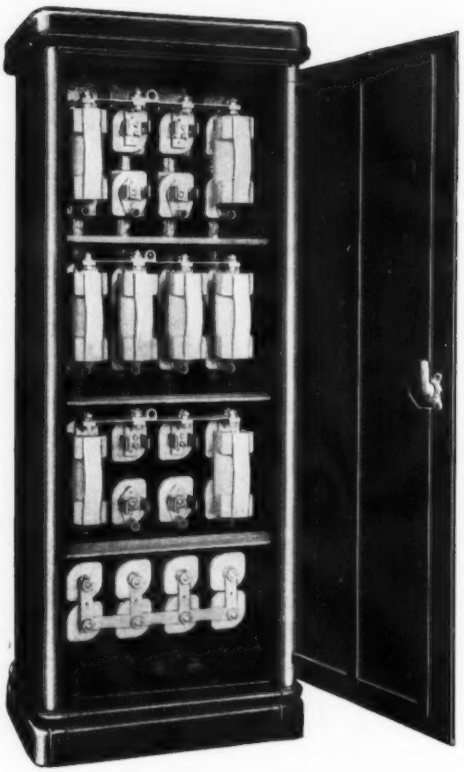

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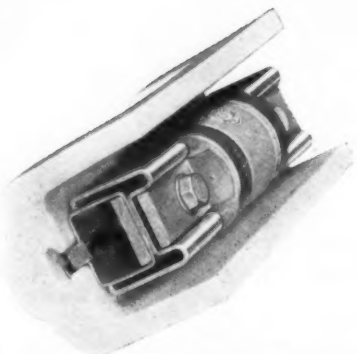

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The English Electric Journal

Vol. IX. No. 1 MARCH/APRIL, 1938. One Shilling.

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All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, THE ENGLISH ELECTRIC COMPANY LIMITED, STAFFORD.

EDITORIAL.

The first article describes the electric locomotive and motor coaches recently supplied by the Company for the Wellington-Paekakariki and Wellington-Johnsonville lines respectively, of the New Zealand Government Railways. In the first section Mr. H. H. Andrews describes the main line express locomotive, a feature of which is the spring cup quill drive. With this form of transmission the entire weight of the motor and drive is spring borne so that only the dead weight of the wheels and axles is left unsprung. In addition, it gives a flexible drive between the motor shaft and the road wheels. The second part of the article deals with the multiple-unit trains. It is of note that both the electrical equipment and the coaches have been designed and built by the Company ; and this has enabled a new method to be adopted for housing the electric control equipment. The high-tension compartment has been incorporated as part of the underframe structure, enabling valuable economies in space and weight to be achieved.

In the second article Mr. A. M. Pooley gives an interesting review of British Standard Specification 88/1937—Electric

Fuses. The new formula for ascertaining the current rating of a fuse is explained and users of " English Electric " fuses are advised that the time/current curves with which the Company's fuses have always complied are almost identical with those corresponding to the new formula. Thus it it is not necessary to make any material change in the manufacturing policy of the Company and customers may rely upon receiving fuses identical in performance as regards current rating with those which they have obtained hitherto.

The next article describes and illustrates the Watthourmeter Factory at the Company's Stafford Works. Each section, from the machine shop, with its battery of latest type automatic machines, to the final assembly line, is referred to. Particular mention is made of the stringent inspection which every part undergoes at each stage of manufacture.

The final article is devoted to a reprint of a Paper by Mr. A. H. Bent, entitled " Welding in the Electrical Engineering Industry," which was read before the Manchester Local Technical Group of the Electrical Power Engineers' Association.

The Paper outlines the advantages of welded fabrications and deals with the problems which face the designer of such structures. The Author deals with the application of alternating current for arc welding, and concludes with a review of the wide range of structures manufactured in the Electrical Industry which are now fabricated by means of electric welding.

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Electric Locomotives and Multiple Unit Trains for New Zealand Government Railways.

By H. H. ANDREWS, M.I.Loco.E.

The steps taken progressively from 1921 by the New Zealand Government to electrify portions of their railways constitute one of the most interesting chapters of the English Electric Company's activities in railway electrification. Following the first electrification, that of the Otira Pass section, came the supply of locomotives and substations for the Christchurch-Lyttelton section on the South Island. Now, in this article is described the locomotive and motor coaches recently built for the Wellington-Paekakariki and Wellington-Johnsonville line in the North Island.

The electrification to Paekakariki covers the first 25 miles from Wellington of the main line to the north of the island. The maximum grade on the line is 1 in 57, and the section includes the recently constructed Tawa Flat tunnels, totalling 3½ miles in length.

The line to Johnsonville, 6½ miles long, serves a popular residential district. It is a heavily graded line with a considerable portion of 1 in 40.

LOCOMOTIVES.

For the Paekakariki line eight locomotives have been built; the first of them has been built entirely in England, the electrical equipment at the Bradford Works of the English Electric Co., the mechanical parts at Newcastle-on-Tyne by Messrs. Hawthorn Leslie (now Messrs. Robert Stephenson & Hawthorns, Ltd.) and the whole locomotive assembled and tested at the English Electric Co.'s works at Preston before shipment from Liverpool. The remaining seven locomotives are now under construction in New Zealand, the electrical equipment having been manufactured in England, and shipped, together with certain special parts of the locomotives, for assembly there. In addition to these eight, equipments for two similar locomotives to supplement the existing service in the Otira tunnel section have been shipped for erection on mechanical parts being constructed in New Zealand.

All these locomotives are of the 2-8-4 type as illustrated in Fig. 1 and Plate I shows the sectional elevation. The salient particulars of these locomotives are given in the following table :—

Gauge	3 ft. 6 ins.
Wheel arrangement ...	2-8-4.
Weight in running order ...	88 tons.
Horse-power (one hour) ...	1,240.
Tractive effort (one hour)...	18,000 lbs.
,, ,, (maximum)...	34,000 lbs.
Maximum speed	55 m.p.h.
Line voltage	1,500 volts D.C.
Number of traction motors	Four.
Transmission system ...	Spring cup quill drive.
Control Voltage	120 volts D.C.
Control System	Electro-pneumatic.
Brakes	Westinghouse air brake, Type A.7 E.L.
Train heating boiler ...	Sentinel, evaporating 1,250 lbs. of steam per hour.
Service	250-ton passenger train—55 m.p.h. 500-ton goods train —45 m.p.h.

As will be noted, the locomotives have to be capable of a very variable duty, dealing with both freight and passenger traffic, on grades up to 1 in 57; further there is an axle load limit of 16 tons. With these varying factors, and taking

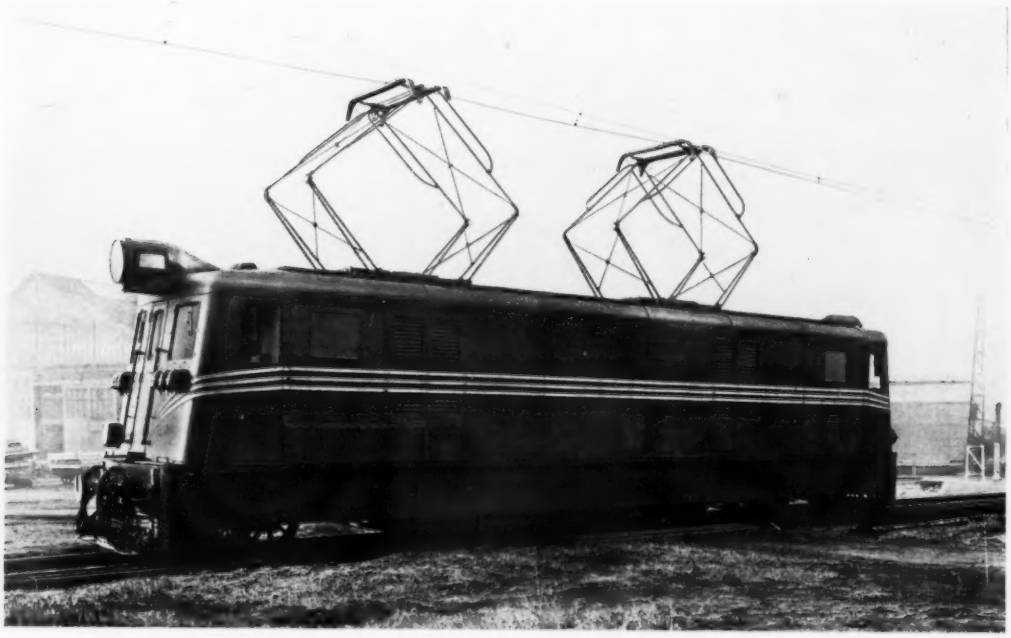


Fig. 1.—88-ton, 1,240 h.p. Main Line Express Locomotive.

into consideration the possibilities of extended duties in the future, this type of locomotive was decided on as representing the best all-purpose locomotive to suit the conditions.

Mechanical Portion.

The main frame of the locomotive is built up of two 41 ft. 10 in. rolled-steel slabs 4½ in. thick. The side frames are riveted at each end to end-frame castings carrying central buffing and draw-gear of standard New Zealand Railway pattern. Intermediate cross-frame stays also serve as supports for the main traction motors which are rigidly secured to the locomotive structure. The axle-box horn guides are fitted with renewable wearing strips of manganese steel, and the cast-steel axle boxes are fitted with S.K.F. roller bearings.

All springs are of the laminated leaf type; compensation is provided between all the driving axles and the pony axle. The bogie is not included in the compensation scheme but the bogie axles are equalised in the usual manner. Both the pony truck and bogie truck are provided with swing link suspension, sufficient transverse displacement being allowed to ensure satisfactory running on five chain curves.

The superstructure of the locomotive is of sheet-steel on tee section framework. It is subdivided into a driving compartment at each end, a boiler compartment, and an equipment compartment with a corridor communication along one side connecting the two driving compartments.

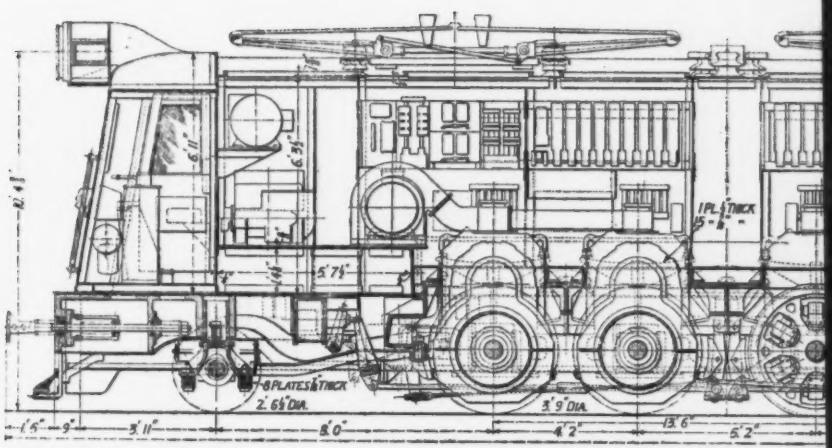
Motors and Driving Gear.

The motors, each of 310 h.p. at the one hour rate, are of standard forced-ventilated series type, connected in pairs in permanent series. The motors are rigidly bolted to locomotive frame stays and spur gearing consisting of a 19-tooth nickel-steel pinion and a 71-tooth gear wheel is provided between the armature and a quill concentric with the driving-wheel axle.

The quill transmits the motor torque to the axle through springs which give flexibility to the

NEW ZEALAND GOV

WELLINGTON—PAEKAKA

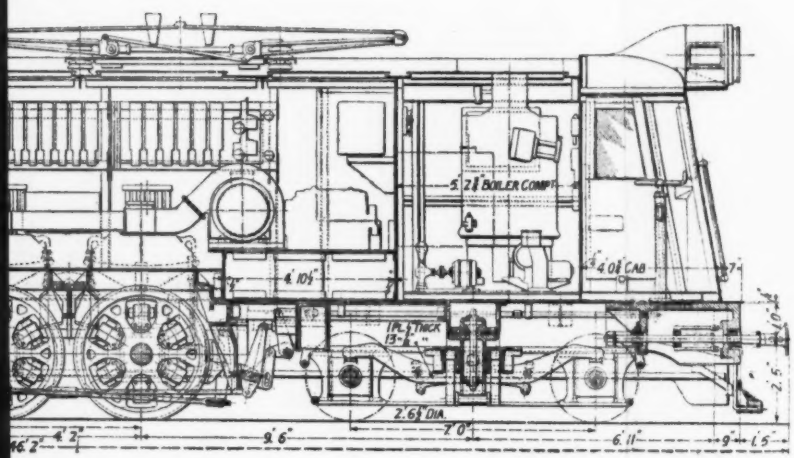


Main Line Express Locomo

Vol. IX, No. 1, Mar.-Apl., 1938.

ERNMENT RAILWAYS

RIKI ELECTRIFICATION



tive—Sectional Elevation.

PLATE I

drive. The entire weight of the motor is thus spring borne, leaving only the dead weight of the wheels and axles unsprung. The quill consists of a hollow steel shaft fitted over the axle between the road wheels and carried by bearings supported from the motor frame, thus ensuring that the quill will always remain parallel to, and at a fixed distance from the armature shaft. The solid steel gear wheel is shrunk on to a cast-steel centre, keyed to one end of the quill.

Clearance is provided between the inside of the quill and the axle to allow for both eccentric and angular displacement of the latter due to the movement of the axle boxes in the horn blocks. At each end of the quill a set of six spring cup brackets is carried. These brackets are secured to suitable faces, respectively in the flange remote from the gear wheel and the gear wheel centre.

The torque of the traction motor is transmitted from the quill to the brackets by means of radial keys and each bracket is secured to the quill by means of two studs which do not transmit any forces. Centrifugal force is taken by spigots and the bracket faces. These brackets project between the spokes of the driving wheels and carry the spring cup units which transmit the motor torque to the driving wheels.

A spring cup drive unit consists of a housing containing a strong compression spring, which is held in place by two case-hardened steel cups fitted over each end of it ; these slide in case-hardened bushings at each end of the housing. The cups are provided with shoulders which engage the inner faces of the bushings, thus limiting the outward travel. The inner faces of the cups are adapted to engage before the spring goes solid under extreme compression. The spring is of the highest grade spring steel and is only moderately stressed ; provision is made for injecting lubricant (grease) into the housing.

Each of the cup drive units engages, in either direction of locomotive travel, with the spokes of the driving wheel to which are welded hardened steel plates to take the thrust. When free the cups are slightly clear of these pads. The pads are of sufficient area to allow a considerable amount of freedom of relative movement between the quill and the axle.

The motor and drive is illustrated in Fig. 2.

The advantages claimed for this type of drive are :—

(1) The springs are only subjected to pure compression stresses and do not experience any twisting or shear effects, thus the duty they are called upon to perform can be accurately predetermined.

(2) Each cup drive unit can be removed and replaced separately without dismantling any other part, either of the quill or the road wheels.

(3) Adequate lubrication both of the moving parts and of the driving unit itself and of all running surfaces is provided.

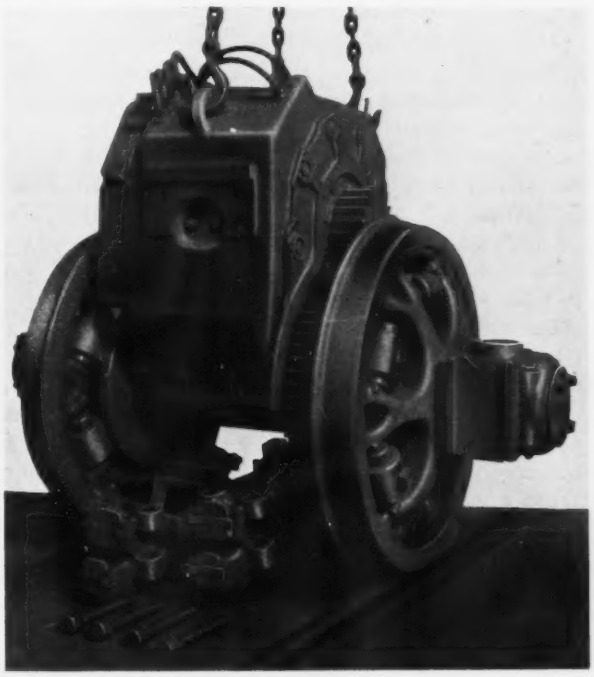


Fig 2.—Track wheels, showing spring cup Quill Drive.

(4) In the event of a spring breaking, the broken parts remain enclosed in a cup and cannot cause damage to other parts of the mechanism. In an emergency, the gear would continue to operate for a time with a broken spring.
(5) None of the bolts is subjected to shear or bending stresses.
(6) The torque is transmitted direct to the road wheel spokes.
(7) The drive provides resiliency between the gear and road wheels.
(8) The whole of the spring cup quill drive is open to easy inspection.

Roller bearings are provided for the armature shaft of the traction motors.

The motors are forced ventilated by motor-driven blowers which draw the cooling air through metallic filters in the locomotive sides. The air passes via sheet-steel ducting to the motor air intake and is discharged through screened outlets at the pinion-end of the motor frame.

Control Gear.

The control gear is of the unit switch type, electro-pneumatically operated. A bank of four line switches and 22 contactors, arranged for series parallel control provides a total of 23 notches, of which six are running notches, viz., full series and two weak field positions, full parallel and two weak field positions. The four line switches are disposed two in series with each pair of motors.

Current is collected by two double-pan pantographs, electro-pneumatically controlled from each driver's cab.

The main power circuit from the pantograph passes through a high-speed current limiter, normally short circuiting a limiting resistance. When opening, on excessive or sudden current rise, the limiting resistance is introduced and the circuit is finally ruptured by the line switches. Ordinary overloads are dealt with by the line switches alone.

The master controllers are of the drum type, operated by a notch-by-notch handle on a toothed quadrant, and mounted in each driving position. A dead-man pedal is incorporated with the driving positions. The control circuits are governed by an air pressure valve, so as to render them inoperative until the air pressure in the brake system has attained a pre-determined value.

The 1,500/120 volts motor generator set, the two 1,500-volt blower motors, and the 1,500-volt compressor motors are jointly protected by an auxiliary circuit breaker and individually by fuses. The locomotives are provided with couplers for multiple unit operation.

Brakes.

The locomotives are fitted with Westinghouse type A.7E.L. automatic and straight air brakes, and in addition, a hand brake at each end of the locomotive can be brought into operation independently of the air brake. The air-brake system is energised from two 38 cu. ft. compressors each driven by a 1,500-volt series type motor.

Air-operated sanding gear is provided.

Steam Boiler.

An oil-fired steam boiler manufactured by the Sentinel Wagon Works, for heating the passenger trains, is housed in each locomotive. This boiler is capable of evaporating 1,250 lbs. of steam per hour at 40 lbs. pressure. The oil firing and water feed are fully automatic. Water tanks, holding 400 gallons of water are built into the underframe of the locomotives.

MOTOR COACHES.

The contract for the supply of six two-coach units for the suburban service between Wellington and Johnsonville was placed with the Company concurrently with that for the Paekakariki locomotives. Each unit comprises a motor coach and a trailer. The motor coach can, if required, operate alone, or units may be made up into four, six or eight-coach trains, operating in multiple unit.

A very special feature of the contract lies in the fact that both the electrical equipment and the coaches have been designed and built by one company, thereby ensuing undivided responsibility. This has afforded an opportunity to effect

a new method of housing the electric control gear in the motor coach. The equipment was manufactured at Bradford, and the coaches at Preston, where they were finally assembled and tested.

Fig. 3 illustrates the general appearance of the completed unit, the main features of which are tabulated below :—

Gauge of track	3 ft. 6 ins.
Ruling grade	1 in 40.
Train make-up	Each unit comprises one motor coach and one driving trailer. Four units can be run coupled together as one train.
Length of coach	60 ft. over headstocks.
Passenger seats, motor coach	68.
Passenger seats, trailer coach	73.
Weight of train unit (without passengers)	67 tons.
Horse-power (one hour) per motor coach	660.
Horse-power (continuous) per motor coach ...	480.
Number of traction motors	Four.
Maximum speed	55 m.p.h.
Normal acceleration ...	1.3 miles per hour per second on 2½% grade.
Line voltage	1,500 Volts D.C.
Control voltage	120 Volts D.C.
Control system	Electro-pneumatic multiple unit, automatic acceleration.
Number of driving positions	Motor coach—two. Trailer coach—one.
Brakes	Westinghouse electro-pneumatic.

Coaches.

The coach underframes are of all-steel welded construction. Owing to the requirements of the steps provided at the passenger entrances, the

Fig. 3.—One of the Multiple Unit Electric Trains.

frames are built up of three sections ; the centre portion sole bars being of Z section and the two end portions of rolled-steel channel. At the two passenger entrances these underframe sections are joined by channel flitch bars forming a step, and an angle steel truss welded to the undersides of the flitch bars gives the necessary stiffening to the broken underframe construction.

The main body pillars are of 14-gauge copper bearing steel of U section, braced by similar section rails. Where extra strength is required, as in the case of door pillars, light rolled-steel joists are used. The roof sticks and longitudinals are of 18-gauge pressed U section, and the whole of the framing is welded together with suitable stiffening gussets where necessary to give rigidity to the structure.

The side and roof panelling is of 16-gauge copper bearing steel, welded to the body structure. The inside of the panelling and of the body framing is sprayed with an adhesive and then covered with wool flock for the purpose of reducing noise.

Dovetailed sheet-steel flooring is welded to the underframes, the dovetailed section of the sheeting providing a locking device for the Induroleum compound floor laid on top.

The interior panelling is carried out in light brown rexine, the wood mouldings are polished mahogany, and all interior metal fittings are chromium plated.

The coaches are heated electrically by ten 500-watt heaters fitted along each side of the coach. Each heater is wound for 150 volts, the set of 10 in series on each coach side being supplied from the line. Each trailer coach is supplied from one adjacent motor coach.

The coach lighting is supplied at 120 volts from the motor generator set and battery. Provision is made for emergency lighting from the battery only, for this purpose one-half the coach lights together with the headlight, tail and marker lights are connected direct to the battery.

The passenger entrance doors are electro-pneumatically operated and their opening and closing is under the control of the guard, who can operate all doors on a train from any passenger entrance, where door control boxes are located. These door control boxes are inoperable, however, without the use of a guard's key, it is not possible therefore, for the doors to be opened or closed by passengers.

A third push button in the door control boxes enables the guard to give the driver both light and buzzer signals to indicate that the train is ready to start. As a further safeguard, however, a power control relay interrupts the control supply until all doors are completely closed. This relay may be short circuited by a sealed switch, in the event of a failure of the door gear making it impossible to start a train.

Bogies.

The bogies are of welded plate-frame construction with plate and rolled-steel cross members. The design incorporates a swing bolster with a cast-steel centre pivot and cast-iron side bearers, and supported on double-helical springs. The axle-box guides are fitted with renewable manganese steel liners. The bearings are S.K.F. roller type, the boxes form seatings for the laminated leaf bogie springs. Adjustable screwed hangers secure the ends of the springs to the bogie side frames.

Brakes.

The coaches are fitted with Westinghouse interlocked electro-pneumatic brakes. There is one brake cylinder, fixed to the underframe per coach, from which normal brake rigging applies the braking pressure to brake blocks on each side of each wheel.

Air pressure is supplied from a 25-cubic feet Westinghouse compressor driven by a 1,500 volt electric motor.

The coaches are fitted with track-operated automatic train stops, trip gear being secured to bogie axle boxes at both ends of the motor coach and at the driving end of the trailer coach.

Motors.

The two traction motors in each bogie of the motor coach are connected in permanent series for a contact wire pressure of 1,500 volts D.C. Each motor has a 1-hour rating of 165 h.p. 750 volts and has one weak field tap.

The motors are nose suspended with rubber blocks in the two trucks of the motor coach ;

they drive through spur gearing consisting of a 17-tooth chrome-nickel-steel pinion and a 63-tooth sprung gear wheel. The gear wheel has a cast-steel boss and a two-part fish-plated chrome-nickel rim, power being transmitted from rim to boss through two helical springs which cushion the drive and relieve the motor of much of the road shock.

Roller bearings are provided for the armature shaft, and sleeve bearings for the axles.

The motor is self-ventilated, the cooling air is drawn in through metallic air filters mounted in the coach side. The air passes via sheet-metal ducting and a flexible leather bellows to the motor air intake and is discharged through screened outlets at the pinion-end of the motor frame.

Control Gear.

The control gear is of the unit switch type, electro-pneumatically operated. A bank of four line switches, connected two in series with each pair of motors, and 16 resistance and field contactors which are automatically controlled, provide the necessary accelerating notches. The master controller is provided with a shunting notch and three running notches, namely, full series, full parallel and weak field.

The whole of the 1,500-volt control gear is mounted in a specially designed interlocked high-tension compartment under the coach floor. This compartment is an innovation in undercar mounted equipment, in that it has been incorporated as part of the underframe structure and has enabled valuable economies in space and weight to be achieved. The space factor was one of great importance as the broken underframe construction, required to provide steps at the passenger entrances, minimised the length of underframe available for mounting equipment, if adequate provision were to be made for easy accessibility for maintenance purposes. This feature has been given considerable attention in the layout of the switch groups and relays, and it may be claimed that the maximum of accessibility has been provided, the whole of this equipment having been mounted between the passenger entrance steps at one side of the motor coach.

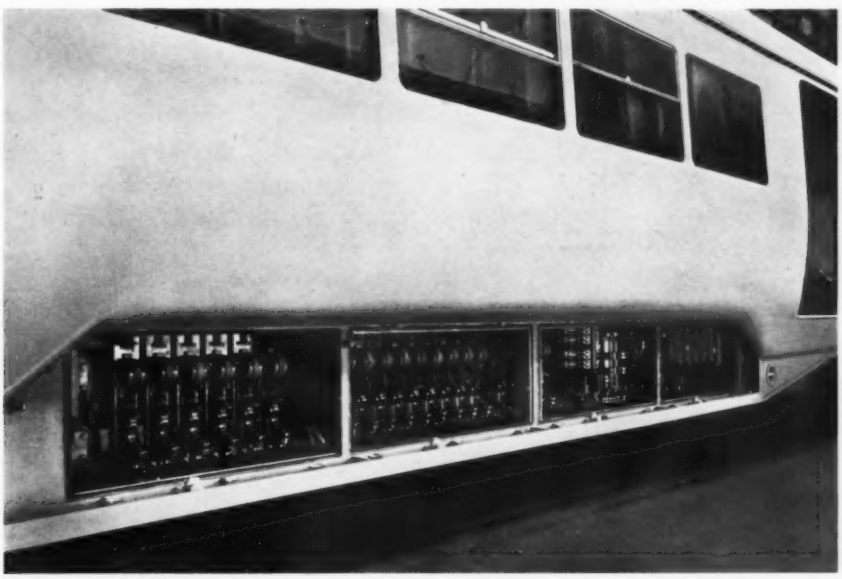


Fig. 4. 1,500-Volt Control Gear, with Inspection Covers removed.

Fig. 4 shows the apparatus exposed for inspection and the general appearance of the control compartment with closed doors will be noted in Fig. 3.

The low-tension supply at 120 volts for control gear, door and brake operation, and coach lighting is provided by a 4 kW motor generator set. Emergency supply is available from a 53-cell lead acid battery, which is arranged to float across the generator terminals. The equipment on the low-tension supply panel includes a voltage regulator and reverse current protection for the battery.

Driving cabs have been provided at both ends of the motor coach and at one end of the trailer coach. Owing to the demand for the maximum of passenger seating accommodation, the cabs occupy only the space between the coach side and the centre end door, a width of three feet and a depth of four feet from front to back being allowed.

The cab equipment includes the master controller, electro-pneumatic brake controller and low-tension controller switches. In addition a colour-light signal box is mounted ahead of the driver giving visual indication that the pneumatically controlled passenger doors are closed for starting. A power control relay is fitted in one cab of the motor coach to interrupt the control supply until passenger doors are fully closed throughout the train.

By means of a push button switch, the driver is given the option of two different rates of acceleration, the switch operating a shunt coil in the current limit relay.

Current is collected from the overhead contact wire by a double-pan light-weight pantograph mounted at one end of the coach roof. The pantograph incorporates anti-fouling tubes and is suitable for operation at heights varying from 12 ft. 3 in. to 18 ft. above rail.

The roof-mounted equipment is completed by a choke coil, condenser-type lightning arrestor and a main fuse.

Both locomotive and motor-coach contracts have been carried out subject to the inspection of Ranald J. Harvey, Esq., M.I.E.E., Consulting Engineer to the New Zealand Government.

Electric Fuses.

Some Observations on B.S.S. 88/1937 and the Factors Governing the Choice of the Type of High-rupturing Capacity Fuse to be used.

By A. M. POOLEY, M.B.E., Manager, Fusegear Section.

The latest B.S.S. 88/1937—Electric Fuses—is a contribution of great value to those members of the electrical industry who are interested in the use or manufacture of electric fuses. A comparison with the previous Specification issued in 1931 reveals the immense progress of the modern high rupturing capacity high-speed fuse in the brief interval of six years. The current ratings dealt with by the Specification have been increased from 100 amps. to 800 amps., and the maximum testing voltage from 250 volts D.C. to 440 volts A.C., and the maximum prospective current from 6,500 to 33,000 amps. Those responsible for the preparation of the new Specification found that colonial and foreign specifications were of little assistance to them. Now that the work has been completed it is safe to predict that it will remain unaltered in all major respects for several years.

In the new Specification, rupturing capacity is dealt with in the following manner: Firstly, there are two voltages for A.C.—250 and 440, and one voltage for D.C.—250. For each voltage range there are four categories, this being deter-

mined by the prospective current of the test circuit. These are specified as follows : 1,000 amps., 4,000 amps., 16,500 amps., 33,000 amps. The latter current at 440 volts is equivalent to 25,000 kVA., 3-phase when one fuse is tested on a single-phase circuit.

The original Specification for current rating stated that the fuse should carry 1.6 × its rated current for 30 minutes, and blow at 1.9 × its rated current within 30 minutes. All " English Electric " fuses up to 100 amps. complied with this Specification, and in order to obtain uniformity throughout the whole range the Company adopted the same Specification for fuses over 100 amps., and up to and including 800 amps. This latter range, of course, was outside the then existing Specification.

The current rating of the fuse is now ascertained in accordance with the following formula, which introduces the expression " fusing factor," this being defined as follows :—

The fusing factor of a fuse is the ratio greater than unity of the minimum fusing current to the current rating. There is a table published, which for cartridge fuses gives the maximum fusing factor as 1.6. It may be any value greater than unity provided that it shall not be greater than the upper limits of the table, which is 1.6. The minimum fusing current may be ascertained from the time/current curves, and is deemed to be the current at the point on the time fusing curve where the time expressed in minutes is numerically equal to 8 × the square root of the rated current expressed in amperes.

When one examines the time/current curves with which the Company's fuses have always complied, against the new formula, it is found that the difference is within recognised manufacturing tolerances. Under the circumstances it is the Company's declared policy to continue manufacturing fuses which comply with their standard time/current curves with which so many users

A section of the Fuse Gear Test Department. The Fuses are brought to and away from the Test Section by means of Gravity Conveyors.

are now familiar, so that customers can continue to rely upon receiving fuses identical in performance as regards fuse current rating with those which they have obtained hitherto.

The Specification continues : " Fuses having fusing-factors not greater than 1.4 shall be described for the purposes of this Specification as intended for over-current and short-circuit protection, whereas those having higher fusing-factors shall be described for the purposes of this Specification as intended for short-circuit protection only."

The use of a fuse for ordinary overload protection for power circuits is not viewed with favour by engineers responsible for the operation of distribution networks. The first duty of the distribution engineer is to give continuity of supply, and, secondly, if a fault does occur, to ensure the automatic and rapid isolation of the faulty section. Shutdowns due to overloading of cables should not and need not occur, and can be guarded against by cheeking the cable loading at the time of maximum demand.

The author of this article has from the inception of the Company's fuse gear business advocated the use of fuses to take care of severe sustained overloads and for short-circuit protection, but does not advocate the use of fuses in power circuits for taking care of ordinary overloads, which can be safeguarded by the control gear.

Consideration of the fusing-factor formula reveals that a fuse rated at 300 amps., having an F.F. of 1.6, can, with an F.F. of 1.4, be rated at 340 amps. The only condition that the fuse has to comply with is that it does come within the temperature rises specified. In other words, the same fuse may be labelled 300 amps. with an F.F. of 1.6, or 340 amps. with an F.F. of 1.4. The cost to the user would be directly proportional to the current rating of the fuses.

Temperature Rise of the Fuse.

Having already dealt with rupturing capacity and rating of the fuse for current-carrying purposes, reference must now be made to a matter of great importance. The new Specification stipulates a maximum temperature rise under full load conditions of 55 deg. C. at the fuse terminals, provided the rise at the cable terminals does not exceed 45 deg. C. in the case of paper-insulated cables and 35 deg. C. in the case of V.I.R. cables, this applying to fuses up to 150 amps. rating. Above this rating the temperature rise for the V.I.R. cable terminals is limited to 30 deg. C.

It should be particularly noted that the temperature rise specified against full load conditions does not take care of the very high temperature which may be reached under overload conditions. The temperature rise under overload conditions does with some types of high rupturing capacity fuses reach very dangerous figures, and the fuse remains unblown. With the patented form of element used in the " English Electric " fuse a dangerously high temperature is never approached even under the severest overload conditions.

The choice of a high rupturing capacity fuse does not rest only with the ability to open the circuit safely—that is an essential quality. There are other factors in connection with the performance that are of almost equal importance which are not always fully appreciated. These are : High speed of rupture ; non-deterioration even when run for long periods under overload conditions ; discriminating properties ; and last, but not least, the ability of the fuse to operate with a safe temperature rise under overload conditions.

The manner in which these different qualities do affect the performance and behaviour of the fuse when used on the distribution networks of supply and large industrial undertakings will be described in the next issue of this Journal.

Watthourmeter Factory at the Stafford Works.

Fig. 1.—General view of Assembly Bay.

The Meter Factory is equipped and staffed solely for the quantity production of the well-known " English Electric " house service Watthourmeters.

The factory is practically a self-contained unit, completely detached from the main works but sharing the excellent services of power, water, clean compressed air and transport available from them. It comprises several single-storey bays (see Figs. 1 and 2) of modern construction with excellent natural and artificial lighting. Provision has been made for extensions when necessary.

The clean, light and airy nature of all the sections is a striking feature and it will be apparent that every effort has been made to provide congenial and healthy surroundings for the employees, together with suitable conditions for the production of first-class meters.

The whole of the Factory is ventilated by washed air supplied by its own self-contained air-conditioning plant, which is under automatic control. This ensures the dust free conditions essential for the production of precision instruments.

The Factory is divided by glazed partitions into well defined sections, each with its own supervisory and inspection staff and equipment.

Fig. 2.—Part of the Assembly Bay.

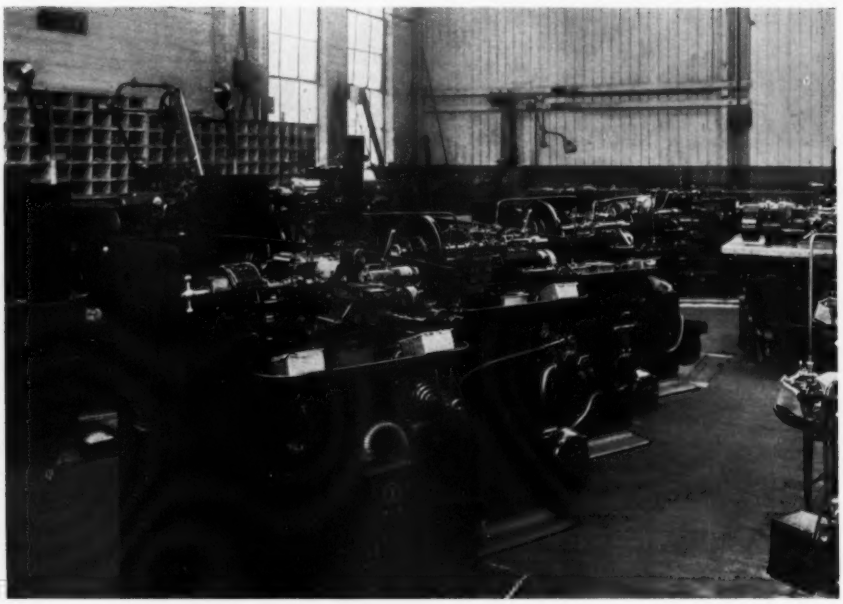


Fig. 3.—Section of Machine Shop showing Automatic Gear-cutting Machines.

Fig 4.—Inspection Department—Microscope Section.

General supervision is facilitated by the single-floor layout and clear gangways.

Raw material is received in an annexe, where it is required to pass stringent inspection before acceptance by the main Stores Department.

The modern design of the watthourmeter necessitates up-to-date production plant, inspection and testing equipment for its efficient and economical production. A short tour through the sections of the Factory will show the extreme care taken at every point to ensure first-class workmanship.

The Machine Shop, a section of which is shown in Fig. 3, represents one of the finest of its type in this country, housing as it does the latest developments of the leading machine tool manufacturers in conjunction with those of the Company's own Tool Designers.

This section is insulated from the remainder of the bay by a sound-proof glazed partition reaching to the roof. In this Shop all the turned components are produced automatically by the most modern plant available; the small tolerances permitted surprise most visitors. Gear and pinion cutting is also carried out here, both by the Peterman and Mikron processes. Drilling, reaming, tapping and so on are further operations necessitating a wide range of ingenious jigs and fixtures.

Each of the machine tools has its individual "English Electric" motor drive and some excellent examples of compact yet readily accessible arrangements are to be seen.

Frequent and systematic inspection of the output of each machine is an important feature and a number of checking fixtures in the Inspection Department deserve special mention.

Binocular microscopes are located at suitable points for detailed examination of the form and finish of the components as produced by the machines. At these stations the microscope

Fig. 5.—Brake Magnet Assembly Section.

DETROIT PUBLIC LIBRARY

Fig. 6.—Register Assembly Section.

magnification is set at 10 or 60 according to requirements.

A Contour Projector with a magnification of 200 is housed in a separate room adjacent to the Machine Shop, to enable quick and accurate checking of tooth forms of counter gears, pinions, worms and similar components to be carried out. This comprehensive optical device also serves to check the form of the gear cutters, hobs and turning tools.

The Microscope Section of the Inspection Department, Fig. 4, with its bank of wide field binocular microscopes with variable magnifications from 10 to 80 is noteworthy. Each instrument has individual illumination and suitable holding fixtures for the particular items being examined.

The Optical Inspection Section is responsible for the examination of all incoming supplies of unmounted jewels from the manufacturers in Switzerland. Special swivelling holders are employed to enable complete examination of all portions of the jewel cup to be made in a quick and searching manner. Further microscope examination is carried out on every jewel mount at each stage of the mounting and cleaning operations.

A number of the optical jigs for the examination of the ball used in the meter lower bearing are covered by the Company's own patents.

In the Finishing Department are housed the latest plant and apparatus for the cleaning, plating and chemical finishing processes.

Baking ovens with thermostatic control are employed in the finishing of steel frames, magnets, etc., and it is of great interest to watch the progress of the work from the trichlorethylene liquor-vapour degreaser through the various operations to the final baking and inspection.

The Permanent Magnet Section, Fig. 5, is of special interest. On completion of the spray finishing and baking processes the magnets are assembled with their support and clamp into one robust single unit. This single unit is a special

and unique feature of the "English Electric" design and it should be noted that it is secured to the meter frame by two screws only, fitting dowels ensuring accurate fitting and replacement without necessitating readjustment of calibration.

The magnets in the assembled stage are saturated magnetically by surge magnetising and are subsequently checked for residual flux in a stroboscopic flux tester.

The assemblies are subjected to several heating cycles to ensure stability and are then sent to "ageing stock" for several months. On withdrawal from "ageing stock" the assemblies are again checked for remanence before being reduced to working strength in a stroboscopic flux reducer. The working strength is considerably less than the remanence strength owing to the twin magnet arrangement and the heavy steel section employed. The resultant assembly is thus thoroughly aged and entirely stabilised ensuring complete freedom from weakening in service.

The Watch-Lathe Section (Fig. 6) illustrates batteries of very ingenious semi-automatic miniature capstans, engaged in jewel spinning and the production and staking of "counter" components. The supervision and inspection of the work in this section is a very important item and here the provision of suitable optical aids is an outstanding feature. Every machine has its individual large-field lens, while the supervision staff and inspectors are equipped with binocular magnifiers or binocular microscopes. Each watch-lathe has its individual motor-drive complete with foot-operated friction clutch which is also an "English Electric" unit.

Before reference is made to the assembly line, the Electromagnet Assembly Section must be referred to. Here it is seen that the laminations are of one-piece design and that the shunt coils are well-finished components with inter-layer insulation of electrical paper. On completion the whole electromagnet is dried, impregnated in a special varnish and baked in much the same way as high-voltage machine components are treated. This process ensures complete freedom from rust-

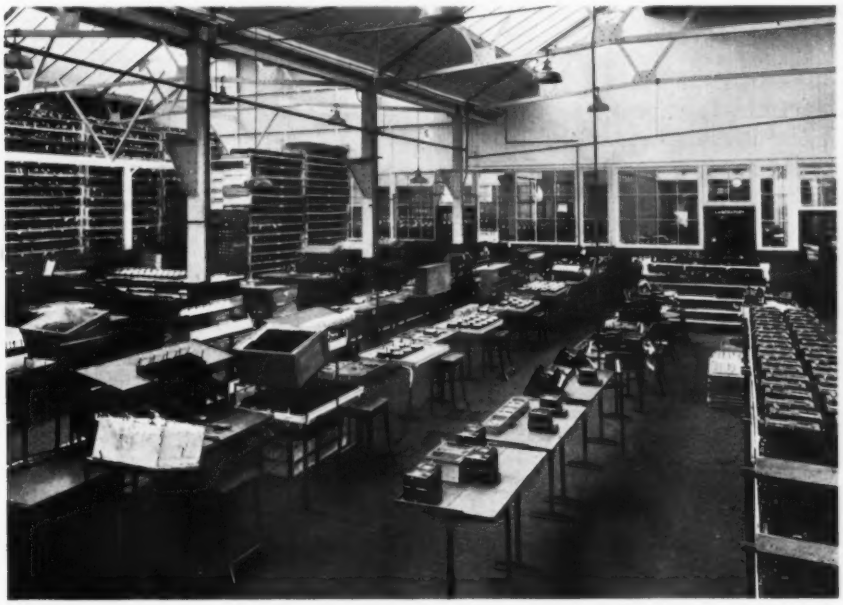


Fig. 7.—Meter Assembly Lines.

ing of the plates and consolidates the coils and insulation, giving a very high insulation resistance value.

The Assembly Section, Fig. 7, is noteworthy chiefly for the clean straightforward layout and the attention which has been paid to efficient inspection. Magnifying illuminated screens are provided at the requisite points to facilitate the examination for cleanliness of air gaps of brake magnets and electromagnets.

Highly skilled meter examiners are located at the end of the line to ensure that each meter is mechanically perfect before being passed into the test room.

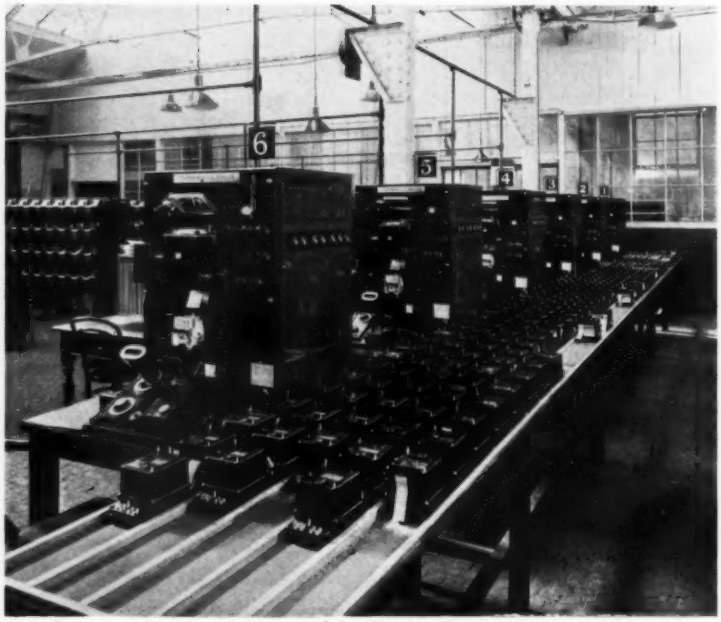


Fig. 8.—A Section of the Testing Department.

Many visitors remark upon the small number of operations actually carried out on the assembly line and the speed at which the meters are completed. This is simply accounted for by the fact that the meter comprises several robust units, each finished and machined with the high degree of accuracy necessary to ensure complete assembly without fitting or adjustment of any description.

The Testing and Research Sections (Fig. 8) will be described in a subsequent issue of this journal and at this stage we outline very briefly certain of the operations.

All meters whether with metal or bakelite case are pressure tested at 2 K.V. for one minute, this test being followed immediately by an Insulation Resistance Test at 500 volts D.C.

Certain tests and adjustments are made at Stroboscopic Stations, followed by the better known test board methods.

A percentage of the output is continually being drawn from the Routine Test Department for complete and searching tests by laboratory methods to compare the performance of the finished meter with the test results on material prior to manufacture.

The Standardising Laboratory adjoins the Test Department for easy co-operation and comparison of results.

The Factory has at its disposal the full resources of the Main Research Laboratory of the Works, the staff of which deal with any special research problems outside the normal capacity of the Meter Factory.

"Welding in the Electrical Engineering Industry."

By A. H. BENT, M.Inst.W.

Read before the Manchester Local Technical Group of the Electrical Power Engineers' Association, 27th January, 1938.

An enormous advance has been made by electric arc welding during the last few years not only in connection with the manufacture of electrical machinery, switchgear, rolling stock and allied apparatus, but in all fields of engineering.

Proved economic advantages had to be established before technical progress could form a new and sound basis for the wide development of welding in the engineering field.

Electric arc and resistance welding, together with the oxy-acetylene process, have now become quite indispensable in the modern engineering shops according to the class of work in hand; in fact, welding to the engineer is now as important as the hammer, lathe, press, or any other tool.

Why has this development in welding become so prominent in engineering? Firstly, because of its proved worth, its great advantage in the majority of cases over the old form of joining together pieces of metal and also, by its adoption for the fabrication of large or small structures in place of castings, or making additions to the castings.

Development in the various phases of welding is progressing at a remarkable rate, and it can be said with certainty that, as yet, even in the modern workshop, all the possibilities and advantages of welding have not been exploited.

Research and practical tests have more than proved the claims put forward for welding, and to-day welding is taking its proper place in all fields of engineering. The advance will be greater still when engineers become more "weld" minded, designing and fully employing welding technique to the particular job, for they are assured that great economical benefit will result.

It is not difficult to weld provided the correct technique is employed, but it requires a great deal of practical experience to apply welding to its best advantage so as to make it a sound business proposition; therefore the co-operation of the Works Superintendent or Shop Manager with the Designer is of utmost importance in order that the best methods shall be used for carrying out the work.

The well-known methods of bolting, riveting or use of castings, will have their application in the future, but engineers have seen how welding can replace these methods in numerous cases, with a resulting increase in strength and often at the same time with a large reduction in weight.

The strength is obtained by the elimination of bolt or rivet holes, and lap joints are often unnecessary, as the parts can be butt welded together, giving an even stress flow from one part to the other. The designer is given freedom in the layout and dimensions of the fabrication, can employ standard sizes of steel plate and sections, strengthen vital parts, eliminate undue stresses in sections and can calculate reasonably accurately the strength of the welded structure.

The important fact emerges that not only is there a considerable saving in material weight, but also in the cost of production, even against a casting. At the present time the employment of standard steels, both plates and sections, means quicker delivery to the workshops, hence earlier despatch to customers. At the same time more work is carried out in the workshop, so reducing overhead charges—a very important factor. To a large Engineering Company the reduction in weight and dimensions effects a considerable saving in cost of transit, especially when shipping abroad.

Referring in particular to the Electrical Engineering industry, there has been an enormous increase in welding in all its many branches. In one particular Works to-day, there are employed some 70 to 80 welders as compared with 4 or 5 some seven to eight years ago. This welding

development has been gradual, following careful design for selected work, research on welding technique, correct type of electrode used for a specific job or material, and an intensive training of the welders under the skilled supervision of the welding expert and Shop superintendents.

The workshops concerned have been gradually changed to suit the new methods of production, for small and large castings have been replaced by welded fabrication. These have resulted in a large reduction in the costs of casting patterns, and in higher speed of production as the time for making the pattern and procuring the casting has been greatly reduced by the use of stock steel plates suitably fabricated by welding.

The essential fact is that a welded fabrication must be *carefully designed from the welding point of view*. Many problems present themselves to the designer, such as : (1) Accessibility for welding, (2) position of welding, (3) effect of welding on the structure with regard to distortion, (4) property of deposited metal, to mention but a few.

To design a structure correctly, the designer must have acquainted himself most thoroughly with such points as—

(*a*) Physical properties of both parent and weld metals.
(*b*) Calculation of weld stresses.
(*c*) Allowable working stresses.
(*d*) Structural arrangements for fabrication.
(*e*) Testing and inspection of welded joints.

He is probably familiar with the characteristics of the parent metal and the fullest details of the electrode can be obtained from the electrode manufacturers with respect to the strength of the deposited weld metal for any particular type of joint. Coated electrodes can be produced to give practically any metallurgical or physical properties in the weld that are existing in any steel or steel alloy, and it is a fairly simple matter to check up these values by producing weld samples and submitting them to laboratory test.

The calculation of stresses in the weld is vitally important for any structure, whether the forces are purely static, or static and dynamic as in a rotating mass. Some helpful information has been published with regard to the method of calculating these weld stresses, but there is still a lack of general agreement on the question, due chiefly to the close relation between the Yield and Ultimate value of Average Resultant Weld Metal, which, of course, tends to keep the safety factor at too high a level. It should be appreciated that there are a large number of variations arising in any weld structures, and chief among them is the type of joint employed, i.e., whether butt or fillet, and also the safety factor connected with either.

Each type of joint has a field of application in a welded fabrication and each its own advantages, but often from the standpoint of economics and of useful life controversy arises as to the correct choice. The two principal joints employed are the butt and the fillet weld, and these are illustrated in Figs. 1 and 2.

Butt Weld.

With a butt weld and assuming parallel plates, the stress is equal to the external load P on the joint divided by the *throat area* of the weld.

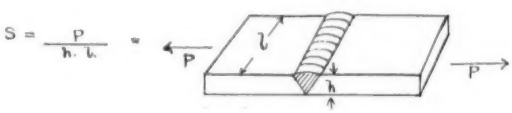


Fig. 1.

Fillet Weld.

It is generally accepted that the basis of calculating the stresses for transverse fillet welds is that the stress at the throat section is principally a normal tensile stress. Fig. 2 illustrates this weld. The stress on the throat section of the fillet weld transmitting a load P is taken as

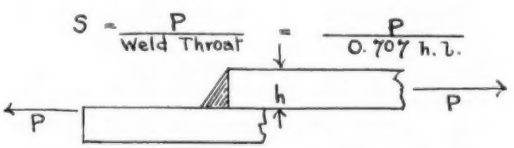


Fig. 2.

assuming that a right-angle weld is made. These are but typical illustrations, and it is not intended to give details of other calculations of these basic welds.

The allowable working stress must be calculated

by the designer according to the type of fabrication and the loads to which it will be subjected.

Careful analysis must always be made of each structure to ensure that it can be fabricated economically. Welds must be designed and located so as to keep distortion of the finished part to an absolute minimum. Fixed or rigid joints should be eliminated as far as possible, otherwise excessive residual stresses will be set up, which may cause cracked welds during fabrication or ultimate failure in service. The design must be such as to permit of a weld being carried out in the downward or horizontal position, as this is by far the easiest and best method of carrying out any particular weld. It must always be remembered that accessibility is a vital factor to the welder, and every effort must be made to facilitate the actual welding work.

It is not always possible to carry out expert tests and inspection of the welded joints, and therefore the design of the fabrication should employ ample safety factor to allow for any small weaknesses which may occur through difficult welds. Also the ultimate design must ensure that the fabrication is as easy as possible from a welding point of view, and that if standard welding technique is followed by the welders under the skilled supervision of the welding foreman, only visual inspection is actually required.

Special methods of testing the weld, such as X-ray or magnetic tests are expensive, and very often difficult to carry out, although in certain cases, such as the welding of a pressure vessel or an oil-filled tank, efficient tests can be carried out on the welds. This is not possible in many other forms of structural welding. It is essential, therefore, that only the highest skilled welders and first grade electrodes, together with high-class plant, should be employed on structures where large dynamic forces, in addition to static forces, are present.

In every field of engineering where welding is carried out, there is development in its technique as applied to the particular product. Engineers have now been able to make a very close study of various reactions that take place when materials are welded together and confident of the results which will ultimately be obtained, have developed a much higher technique for the fabricating of various structures.

In electrical engineering particularly there is a marked advance in pre-machined parts which are welded together with negligible distortion. The effect of this is that the smaller parts can be made in quantities, drilled, machined and shaped in the small engineering shop, afterwards being sent to the welding shop, where they are jigged and welded into position. This effects great economy in production without in any way sacrificing engineering accuracy; also large lathes, drills, and planing machines are released for heavier work, and this really is important in a large concern.

A particular construction in question is metal-clad switchgear containers, the dimensions being approximately 18 in. × 16 in. × 26 in., built of 3/16 in. × 11/16 in. steel plates, and these have been fabricated after each part had been machined and drilled, etc., and after completion of the whole structure the maximum error due to distortion by welding was not greater than .01 in.

To execute successfully a pre-machined or any complicated fabrication, the work must be prepared so that the parts to be welded together are faced up accurately; the necessary clearances are allowed for the expansion and contraction of the welded portion, the welded faces must be free from rust, scale or any foreign matter, as this interferes with the welding efficiency.

The responsibility of the welding shops is certainly not less than that of the designers, and it is imperative that the welding shop layout and equipment should be highly efficient, so as to effect the economies called for by the welding design. Steels of standard, though various sizes come from the suppliers, and these must be cut, rolled and shaped to suit the job. First-class guillotines, presses, plate-bending machines, plate-forming and section rolls, and gas cutting and profile plant must be installed to shape the parts for welding.

The oxy-acetylene or oxy-coal gas cutting plant is highly essential in order to cut and shape accurately the steel members so that the time of

fitting together prior to welding is the minimum, and afterwards machining, if any, is greatly reduced. Large baseplates or rails bonded together, and grouted in the floor, carry the work in the course of welding, and jib cranes and other means are provided to manipulate the structures into the best position for welding. The baseplates or rails form the earthed circuit for the electrical welding supply.

Next, but equally important, must be considered the electrical plant required for arc welding. Welding may be accomplished by either a suitable D.C. or A.C. supply, but as the welding is carried out at low voltage and high current, suitable converting or transforming plant is required. If the welding is by D.C., then usually a motor generator is used, the generator having suitable welding characteristics. If A.C. welding is used, then a transformer to reduce the supply voltage, together with means of obtaining the required welding currents, is essential. Either type of welding plant is suitable for the welding of steel, steel alloys and austenitic steels, and with a correctly designed plant and suitable electrodes a sound homogeneous weld, free from porosity, is easily obtained.

Each welder should have individual and complete control over his welding arc, i.e., he should be able to select and maintain the correct welding current and to be entirely free from electrical interference from other welders using the same welding equipment.

As floor space is an important factor in the welding shops, the welding sets should be as small as possible, though entirely reliable. Single-operator or multi-operator plants can be supplied, but the latter is to be preferred in a large shop with a number of welders, as the first costs show a considerable saving, a higher operating efficiency is obtained, and economy in floor space is effected.

Further, with a multi-operator equipment, although it is designed to supply a certain number of welders each taking a maximum welding current simultaneously, if the load cycle and welding current is fairly small, then it will be possible to increase the number of welders, the limit being obtained when the temperature rise of the supply unit has reached the maximum safe value. The author is aware of at least two A.C. transformer plants, one supplied to a shipyard and the other to a large works, which were actually designed for three operators in accordance with B.S.S. 638, but are now supplying twelve welders without the transformer exceeding a temperature rise of 50 degs. C. in oil.

The advance in welding by alternating current has been equal, if not greater, than that of welding itself. Earlier efforts to weld by A.C. did not meet with too great success, and it was only after careful investigations of the true requirements of the electric arc, together with long research and special design of transformer plant, that A.C. arc welding was accepted by welding experts, as equal to and sometimes superior to that produced by direct current plant. The advent of the British Grid, giving an abundance of alternating current energy at low voltage, stimulated the interest of large engineering firms in the manufacture of A.C. welding plant, as here again, improved economy would be effected as the operating efficiency of this plant is very high; the plant is static, i.e., it has no rotating or moving parts; hence maintenance is negligible, and, further, standard equipment can be produced for weatherproof service.

With a correctly designed A.C. plant, the arc energy is reasonably constant over the complete cycle, and this has been brought about by the design of the plant. Fig. 3 is a reproduction of an actual oscillogram of the welding current and arc voltage of an A.C. plant. This oscillogram clearly indicates how closely the welding current conforms to the ideal wave shape, and that dead

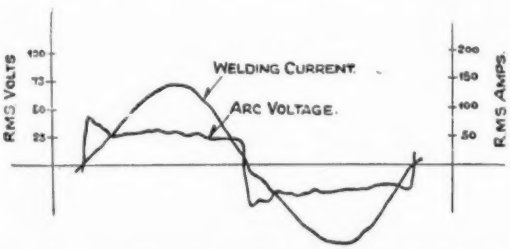


Fig. 3.—Oscillogram of Welding Current and Arc Voltage.

periods in the arc are eliminated ; this condition producing a stable arc, which is easy to control and free from spluttering, enabling a good homogeneous weld to be made at high speed. Fig. 4 shows a typical three-operator transformer plant.

Fig. 5 is a diagram of connections of a multi-operator A.C. welding equipment showing the current distribution under the worst conditions, i.e., when only one phase is loaded. Even with this abnormal condition, by reason of the special connections of the transformer, the current distribution in the primary side is in the ratio of $\frac{1}{2} : 1 : \frac{1}{2}$. Under normal conditions of welding a more symmetrical balance on the welding system will be obtained.

With a correctly designed A.C. plant, unlike that of a spot or resistance welder, there are no high peak currents, due to shorting the secondary, i.e., welding side, either when starting or when the electrode sticks to the work. The current over normal at any welding current should not exceed approximately 10 per cent., so that no disturbance is caused on the supply system, due to impulse load.

Electrical engineering firms who themselves manufacture such A.C. plant, carry out a considerable portion of their welding by the use of their own plant, and therefore they are fully aware of its true characteristics. Magnetic arc blow associated with D.C. welding is entirely eliminated with A.C. plant, enabling welding to be carried out in most difficult holes and corners, etc. In other fields of engineering, such as shipbuilding, locomotive and structural works, A.C. is now rapidly developing, and large ships to-day are being welded together by the use of this plant.

Fig. 6 is a typical shop layout, and it will be noted that in this case the transformer is located between the shop stanchions, effecting economy in floor space. The supply to the individual welding regulators is made through busbar connections running the length of the shop, and the operators, regulators are tapped off at intervals. This is a typical installation of such a transformer plant in any engineering workshop.

Fig. 7 shows the supporting frame for high rupturing metal-clad draw-out type switchgear. The frame on the right-hand side of the photograph is made of cast iron, and on the left is a fabricated steel design, which has now superseded the casting. Apart from the great improvement in appearance, the fabricated design shows the following advantages over the casting :—

(1) The fabricated structure is approximately 60 per cent. of the weight of the cast iron frame.

(2) There is approximately a saving in cost of 15 per cent. by using the fabricated design over the casting. The fabricated frame can be designed to meet electrical requirements, inasmuch as all the low tension terminals, small wiring, etc., are con-

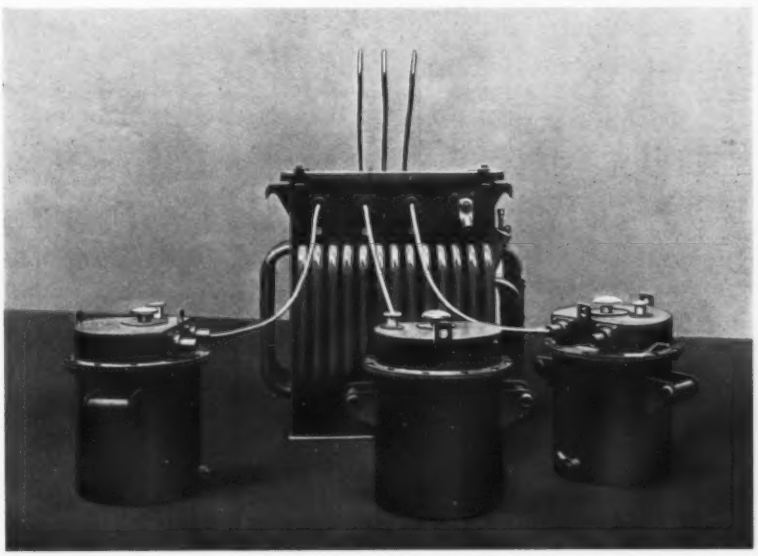


Fig. 4.—Three-operator equipment showing the Transformer and Welding Regulators.

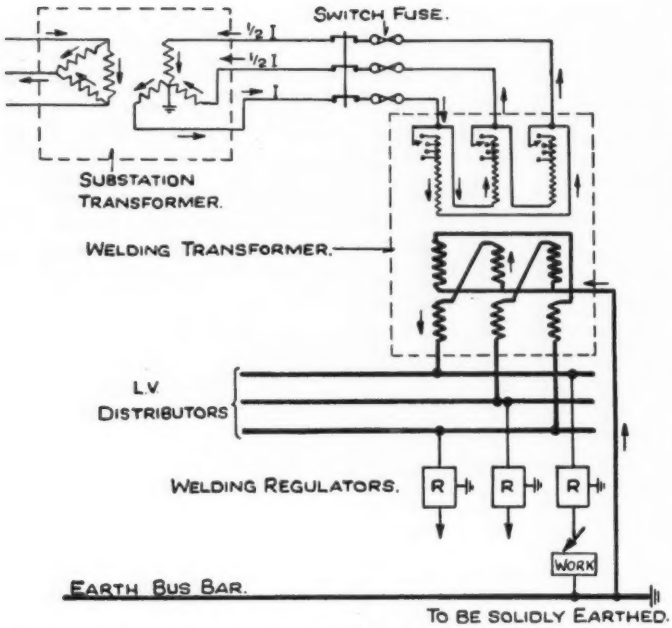


Fig. 5.—Diagram of Connections for Multi-Operator A.C. Welding Equipment showing current distribution with only one phase loaded.

veniently housed in the box and double section of the fabricated frame, thus amply protecting all the small wiring. The small wiring on the cast iron frame would have to be run in special conduit and terminal boxes fitted for the necessary connections.

This fabricated structure is entirely manufactured in the Works from standard steels and a much quicker delivery is effected.

Transformer tanks are now practically all welded and there are some hundreds of welded joints on a reasonably small tubular transformer tank, apart from the welding on the top cover. All tanks are tested for oil pressure and by reason of the sound technique employed in engineering shops, a very high percentage of these tanks pass through pressure test without a failure.

Recently, some large transformer tanks were manufactured on which there was some 2,000 feet of welding. The weight of the tank itself was approximately 13 tons, the dimensions being 230 in. long × 78 in. wide × 105 in. high. The tank cover alone weighed $2\frac{1}{2}$ tons. The tank was completely fabricated and welded in the shops. When complete, and as shipped, the total weight of the transformer was 88 tons and it was lifted by the shackles which were welded to the sides of the tank, no bolts being used.

Electrical Engineering is also deriving much benefit by the use of tubular members in the construction of large frames. Tubular sections have ideal properties for welding, the difficulty in joining tubular members together on to plates or rolled sections being entirely overcome by the application of welding. Further, with the use of tubes, added ventilation can be obtained, a very important factor, or in the case of oil-immersed frames a freer circulation of oil for cooling is permitted, resulting in lower temperatures. Pipe work with many angle joints, bends and flanges as used with the cooling equipments of large transformers, is arc welded and of course, has to be perfectly oil tight under pressure.

Radical changes have been made on medium D.C. magnet frames, these being changed from cast steel to rolled slabs with horizontal joint plates and flanges being welded in. Recently large mill motors have been fabricated, obtaining the necessary mechanical strength against air gap deflection by ribbing the slabs by welding, the cross sections thus obtained being wholly magnetic resulting in a minimum of weight or where this is of no importance, the rolled slab alone can be designed to deal with the flux and the welded-on ribs being used purely for mechanical stiffness. Such economy in design has resulted in as much as 30 per cent. reduction in production costs. A major point of interest and of the greatest importance is that the rolled slabs are absolutely homogeneous and therefore, have true magnetic values, which latter may not be obtained in a

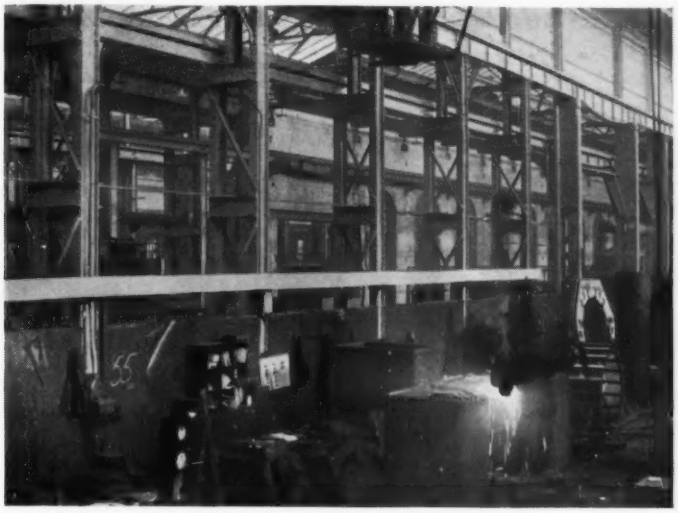


Fig. 6.—Typical lay-out of a six-operator 400 amp. A.C. Welding Equipment at the English Electric Company's Stafford Works, showing Transformer and low-tension Busbar Chamber.

casting due to blow holes and foreign inclusions. The bearing pedestals are also fabricated with every success and at a cost often not exceeding the cost of the pattern only.

Large engine and turbine-driven alternator frames are now completely fabricated and welded together, giving enormous strength and rigidity. The main members of the latter frames are now often of the tubular structure, which so lends itself to welding and permits of additional cooling facilities. Cast iron bedplates have been almost entirely superseded by a welded fabrication and if the main members are suitably folded this eliminates the amount of welding required and adds to the pleasing appearance of the finished article.

A more complex, though exceedingly interesting development is the welding of austenitic material into mild steel when heavy currents are carried through the structure. This applies particularly to the domes of large circuit breaker containers where non-magnetic inserts break the magnetic path around the current terminal, eliminating heat, energy loss, etc. Owing to the widely different physical and thermal characteristics of the steel and inserts, special welding electrodes and technique must be employed in order to obtain a sound homogeneous weld, free from porosity and capable of withstanding a good oil pressure test. Arc welding now accomplishes this work with ease and economy.

These are but a few applications of arc welding in electrical engineering shops; there are scores of others, such as welded transformer frames, switch-gear framework, jigs, etc., in fact welding is now indispensable in all departments of the works. The building up of worn parts, the tipping of worn tools, repair of broken parts, are but a few applications of arc welding on the maintenance side of the factory.

As yet automatic or semi-automatic arc welding

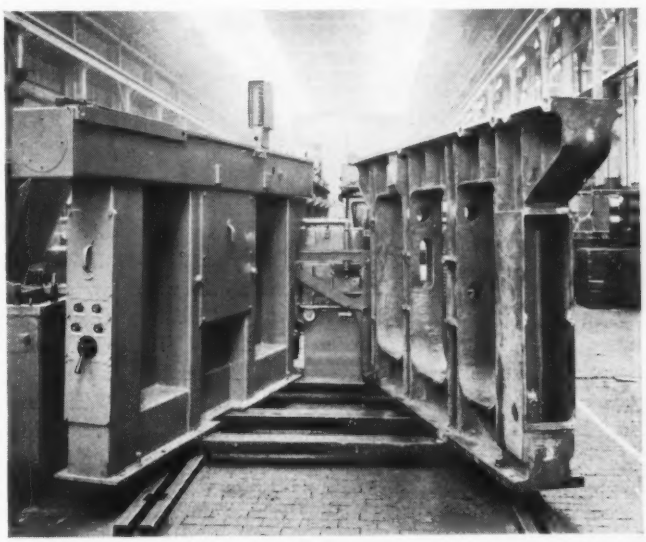


Fig. 7.—2 Pillar-supporting Frames for metalclad draw-out type Switchgear. On the right a cast-iron frame and on the left a welded frame.

is not generally justified as this type of welding can only be economically employed on mass produced parts. There is, however, a field for this form of welding, and with more experience and further developments, its adoption in electrical engineering is assured where large repetition work is carried out.

Spot or resistance welding has its limited sphere, but is certainly used to advantage where small parts are to be located to main members.

Great progress has been made in the welding of rolling stock in all its branches ; whole structures for diesel electrical units are now fabricated by welding. The welding of a four-coach articulated underframe requires exceptional experience and care, owing to its enormous length and weight, but such work is yet another proof of the soundness of arc welding in the industry. The all-metal bus body affords an excellent example of light gauge welding where both arc and spot welding is used. Such constructions reduce dead weight, add to the pleasing appearance, yet are stronger and more reliable in service than the older forms.

Much more could be said as to how welding is assisting in the development of the electrical engineering industry.

Abroad, both on the Continent and in the U.S.A., welding generally is more advanced than in this country. It is thought this is due to the larger scope in general engineering, largely building construction, bridges, etc. However, as far as welding in the electrical engineering industry goes, we are not lagging behind, and this is chiefly due to our earlier approval and use of the coated electrodes.

Up to about five years ago practically all welding in the U.S.A. was carried out with bare wire using D.C. plant, and with electrodes 3/16 in. maximum diameter. Following the excellent results obtained in this country with the coated electrodes, together with the added advantage of higher welding currents, higher efficiency and speed of welding, together with a sounder weld metal, coated electrodes were produced and used in the U.S.A. The advent of this type of electrode has enormously increased the use of A.C. welding plant throughout that country.

Concerning welding generally, the weldability of metals is dependent upon a number of important factors, chiefly metallurgical characteristics, chemical constituents, physical properties, type of electrode used and welding technique employed. A further factor is the treatment prior to and after welding.

The bulk of material arc-welded in the electrical engineering industry is low-carbon steel, which is relatively easy to arc weld, but higher carbon steel, special alloys and non-ferrous metals are also welded, and these present more difficulty. An instance of this was given earlier in the paper when Nirus inserts were welded into mild steel. In each case the results obtained follow a definite reason, and at least a good working knowledge of these factors is of the greatest value to the designer and those directly concerned in the welding of structures, etc.

As a result of the welding operations, metals of all kinds undergo structural changes, these changes being a function of the temperature obtained during welding, the chemical composition of the material, both electrodes and parent metal, and the rate and conditions of the cooling from the molten state.

The effect of these changes on the welded portion depends upon the metal welded.

Hardness and brittleness in the weld and adjacent areas to the weld may be produced, whilst in other cases the corrosion resisting properties may be adversely affected.

It would, therefore, be apparent that the success obtained when welding any metal is a function of the oxidation of the chemical constituents, the vaporisation of the alloying elements, changes in the metallurgical structure, any non-metallic inclusion and the solubility of gases in the weld metal.

The use of the correct electrode, welding current and welding procedure will contribute greatly to the highest efficiency in the weld, but the welder should be given the best type of welding plant, as this is his tool to perform the work required.

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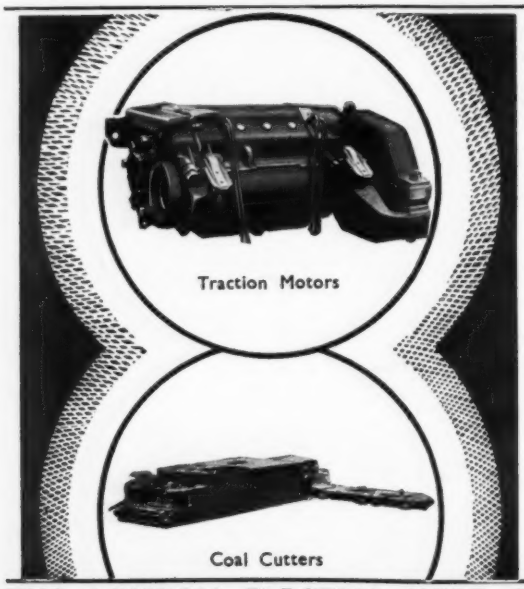

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ESTABLISHED 1783

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